# VENTILATING METHODS AND SAFETY MEASURES USED IN THE TEMPORARY VENTILATION OF THE KING SOLOMON TUNNEL, FRISCO, SUMMIT COUNTY, COLO.

BY R. L. BOLMER AND G. B. FRITTS

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R. L. Bolmer[1] and G. B. Fritts[2]

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1/ Mining engineer, Bureau of Mines, Denver, Colo.
2/ Coal-mine inspector, Bureau of Mines, Denver, Colo.

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## INTRODUCTION

Rapid depletion of our known mineral resources has stimulated exploration for new mineral deposits. Abandoned mines or prospects may prove to be commercial in today's economy. Often it is necessary to revaluate such properties. Some of these may be inaccessible because of caving of flooding. Many, however, remain in good condition, except that over the years the air in the workings has become depleted of oxygen. Each year the Bureau of Mines receives numerous requests for aid in entering old mines, the air in which is incapable of supporting life. Requests of many individuals who wish to examine or explore such places with the help of the Bureau's self-contained oxygen breathing apparatus have been denied because of the hazards involved in the use of this equipment for such purposes. The distance to be traveled in irrespirable gases may be too great for safety; under favorable conditions, a round trip of 2,000 feet from fresh air is the maximum distance that may be traveled.3/ The use of such equipment is hazardous unless a team of at least 5 men thoroughly experienced in its use is provided; and when extensive traveling from a fresh-air base is required, a reserve team should be provided.3/

Usually, the apparatus is requested for use in exploring workings having only one surface connection, as mines having more than one opening usually are more easily ventilated, and in some natural ventilation is sufficient or can be made so by cleaning out obstructed openings.

In mines having only one opening to the surface, the natural air flow is confined principally to that induced by barometric changes and flowing water, and generally the air is irrespirable if the mine has been idle for a long time. This is most likely to be the case where workings contain considerable timbering or where oxygen depletion occurs from oxidation of the strata. In such places it is necessary to provide fresh air by mechanical ventilation in such quantities as will make the mine atmosphere respirable. Often the lack of electric power, the cost of suitable fans and tubing, and the installation costs make standard ventilation procedures impracticable for a temporary ventilating job. The King Solomon Tunnel was an example of the above. The United States Geological Survey desired to ventilate the tunnel temporarily but considered the cost of providing electric power, suitable fan and ventilating pipe, and the installation costs as prohibitive.

The method of ventilation adopted and the safety measures taken during the progress of ventilating, as described herein, should prove of interest to individuals having similar ventilating problems.

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3/ Grove, G. W., Self-Contained Oxygen Breathing Apparatus: Bureau of Mines Handbook, 1941, pp. 174-176.



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## SUMMARY

The King Solomon Tunnel or mine consists of an adit crosscut 5,728 feet in length, extensive laterals, raises, winzes, and stopes, and the adit portal is the only outside connection. The mine had been idle since 1915 and was accessible for only about 700 feet from the portal of the adit because of oxygen-deficient air. The U. S. Geological Survey desired to examine this tunnel to supplement surface geologic investigations. Preliminary sampling of the tunnel air in as far as 700 feet from the portal had shown virtually no carbon dioxide. Questioning of a former worker in the tunnel disclosed no evidence that carbon dioxide had issued from the underground strata.

A conference between officials of the Physical Exploration Branch of the Geological Survey, of the Mining and Accident Prevention and Health Divisions of the Bureau of Mines, and J. H. East, Jr., Regional Director of the Bureau of Mines was held to determine means of tunnel access. Conclusions resulting from the conference were (1) that the cost of a fan, ventilating pipe, power, and installation were prohibitive for a temporary job, and (2) it seemed probable that the tunnel could be ventilated progressively during exploration by the use of compressed air, and that an available Bureau of Mines portable, gasoline-driven, air compressor and 2-inch pipe would serve the purpose.

To assure that the pipe-laying crew would be working in good air, the Bureau of Mines agreed to furnish an engineer with necessary equipment for determining the quality of the mine air as ventilation proceeded.

It was problematical whether the compressor would furnish enough air to ventilate the workings as fast as the pipe could be laid. However, results showed that by operating the compressor 24 hours a day and laying pipe 8 hours a day the men were always working in good air.

Pipe was transported into the tunnel by burro, later supplemented by a horse as the distance increased. Actual ventilation was started on August 31, 1950, and was completed on September 20, 1950, at a cost of $1,536.09, not including the moving of the compressor and pipe to and from the job. A crew of five men, consisting of a foreman, 3 compressor men, and 2 laborers, was employed.

## ACKNOWLEDGMENTS

The authors gratefully acknowledge the cooperation of the Physical Exploration Branch of the U. S. Geological Survey who undertook the project; W. P. Huleatt, Chief of that Branch, who supplied the cost data; D. F. Kent, of the Mineral Deposits Branch of the Survey, who mapped and sampled the tunnel and from whose data the map included in this report was taken, and Walter Byron, owner of the King Solomon property, who permitted the investigation.

## LOCATION

The King Solomon Tunnel is 1-1/2 miles west of Frisco, Summit County, Colo., in the Tenmile Mining District. The portal, waste dump, and surface



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buildings are readily visible from U. S. Highway 6, which parallels the north side of Tenmile Creek Canyon west of Frisco. The portal is on the steep south slope of the canyon that forms the northern boundary of the Tenmile Range. It is about 130 feet above the creek bed at an elevation of 9,280 feet. The unimproved access road branches from U. S. Highway 6 at the western limits of Frisco and follows the abandoned narrow-gage C.&S.R.R. grade up the south side of Tenmile Creek Canyon. The portal is 1-1/2 miles distant from the U. S. Post Office at Frisco.

## HISTORY

The King Solomon property had been idle for nearly 35 years. The tunnel was reported to be 6,300 feet long, but was not accessible because of oxygen-deficient air, and only incomplete maps and records were available. The tunnel's location through the northern end of the Tenmile Range made its examination desirable to supplement the surface geologic investigations of the Tenmile District being completed by the Mineral Deposits Branch of the U. S. Geological Survey. A preliminary examination on January 10, 1950, revealed oxygen-deficient air in the tunnel 700 feet from the portal. A flame safety lamp was extinguished at this point, and analyses of samples of tunnel air taken beyond that point revealed a deficiency of oxygen but no appreciable amount of carbon dioxide.

## METHOD OF VENTILATION

Following this examination, a conference was held in which the following participated: W. P. Huleatt, Chief of the Physical Exploration Branch of the U. S. Geological Survey, J. H. East, Jr., Regional Director of the Bureau of Mines, and officials of the Mining Division and the Accident Prevention and Health Division of the Bureau of Mines.

At this conference, estimates were made of the cost of bringing electric power to the property, the cost of a fan with enough pipe to reach the face, and installation costs. It was concluded that the estimated costs were prohibitive, considering the temporary nature of the project. As an alternative, it was suggested that a portable, gasoline driven air compressor and enough 2-inch pipe could be borrowed from the Bureau of Mines and an attempt made to ventilate the workings with this equipment. The problem of blowing out air containing a concentration of carbon dioxide with the relatively small volume of air the compressor would furnish was discussed. However, the preliminary examination showed no appreciable amount of carbon dioxide in the oxygen-depleted mine air 750 feet from the portal. Questioning of a former worker when the mine was in operation did not reveal that carbon dioxide had issued from the underground strata. The Exploration Branch of the Geological Survey decided to try the scheme, using the compressor and 2-inch pipe, although it was problematical how long it would take because of the small volume of air the compressor would furnish. The Bureau of Mines agreed to furnish an engineer with necessary equipment on the project to assure that men laying the pipe would be in respirable air at all times.



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## PHYSICAL FEATURES

The King Solomon Tunnel, strictly speaking, is an adit, as it has only one opening to the surface. Driven on a straight course of S. 11°-30' E. under the northern extension of the Tenmile Range, its breast lies directly below No. 1 Peak of the range. It is a crosscut adit driven for the most part through a hornblende-biotite-gneiss that comprises a part of the Idaho Springs Formation. The principal veins intersected strike roughly northeast-southwest and dip steeply toward the southeast. Drifts had been driven along nine of these veins for varying distances in either one or both directions from the tunnel. Altogether, 2,650 feet of laterals were accessible. The breast of the tunnel was found to be 5,728 feet from the portal.

The veins for the most part were narrow, and in only two instances were stopes found along the laterals. (Reference is made to fig. 1.) In 1 East Drift, stoping was encountered for about 55 feet along the vein; its height was not determined. In 6 East Drift, a larger stope was encountered. The stope was accessible only 90 feet along the drift because of the partly caved drift and the unsound hanging wall. The ore had been mined about 5 feet in width, probably by a shrinkage method, to a height of about 100 feet on the dip.

There were several raises off the laterals, but they did not extend to any height. Two winzes were found. In 1 East Drift, a winze had been sunk on the vein and below the stope mentioned; at the junction of the tunnel and 6 West Drift, a vertical winze had been sunk. Both winzes were flooded to the tunnel level, and no attempt was made to investigate them. The No. 5 West Drift was inaccessible, as it was caved and cribbed tight at the tunnel intersection.

Very little timber had been used, and the back and walls in the tunnel, and for the most part in the laterals, were sound. Timber in the stopes and raises had rotted and fallen out, allowing a small amount of loose material to come down. The tunnel made a small quantity of water, but no perceptible dripping was noticed except in the breast of 9 E. Drift near the end of the tunnel; however, the walls of the tunnel were damp for nearly their entire length. A ditch along the side carried off water readily, but the bottom of the tunnel remained muddy.

The tunnel was driven for the most part to a 5x7-foot cross section. In certain areas this was increased to a 7x10-foot cross section. All of the mine track had been removed from the tunnel, and pipe had been removed to a point 4,475 feet from the portal; however, 2-1/2-inch pipe in place and in good condition was discovered at that point. It extended to 5,660 feet and was utilized to ventilate this last section of the tunnel. In removing the mine track, some of the ties had been dislodged, and the floor of the tunnel was rough and uneven.

## LOG OF OPERATIONS

Preliminary work in preparation for actual ventilation of the tunnel began on August 22, 1950. A foreman and a compressorman were hired and



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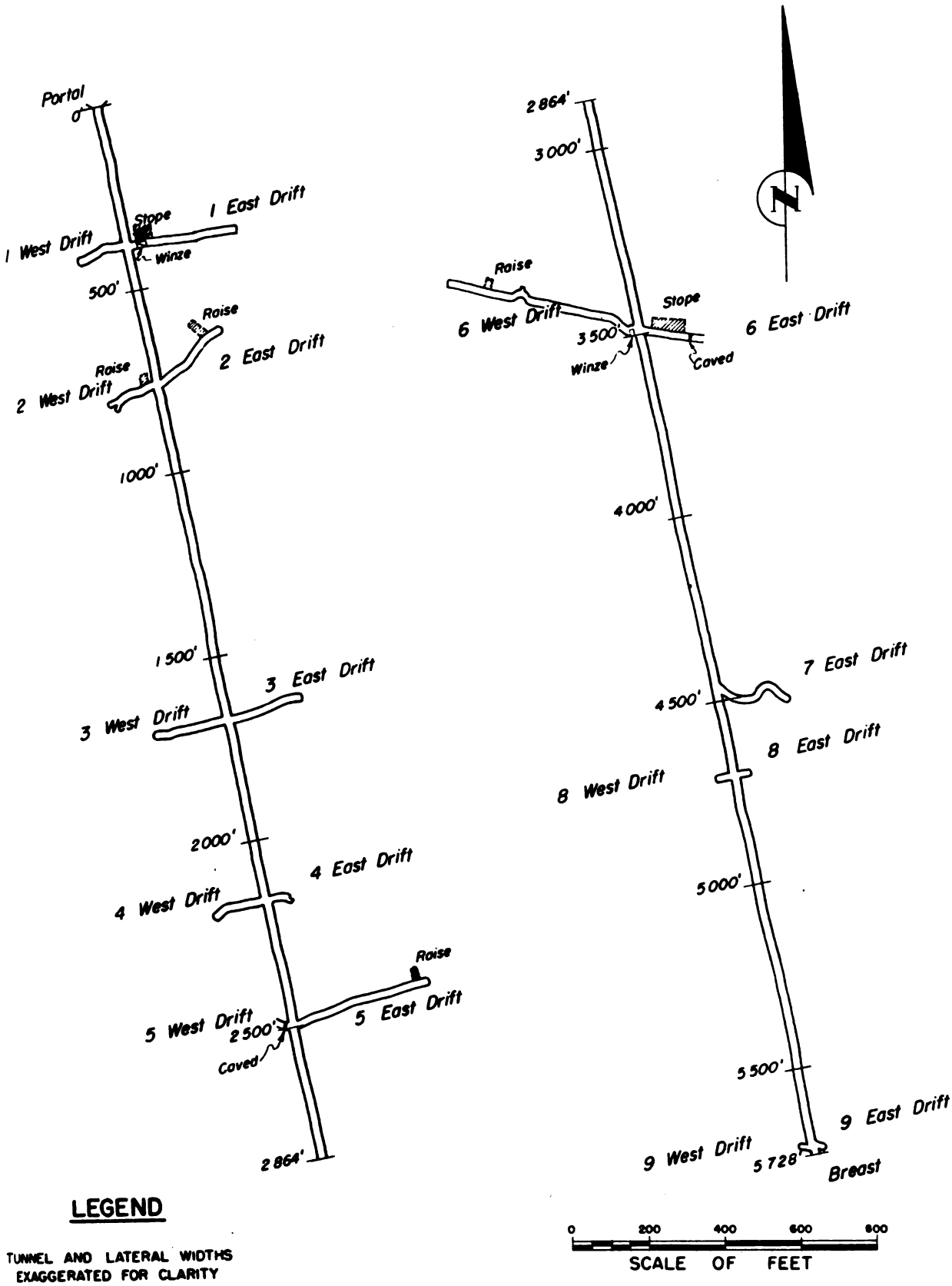


**Figure 1. - Plan map of King Solomon Tunnel, Summit County, Colo.**

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sent to Salt Lake City, Utah, for the compressor. The access road to the portal was rehabilitated. Seven thousand three hundred and fifty feet of 2-inch pipe was brought from Leadville, Colo., and the compressor was set up. This work was completed by August 30, 1950. Two laborers had been added to the crew on August 29, 1950. (Reference is made to table 1.)

The actual laying of pipe began on August 31; 765 feet of pipe was laid, which included 84 feet across the dump to the portal. The pipe extended 681 feet from the portal at the end of the shift. On September 1, 5, and 6, 315, 483, and 403 feet, respectively, was laid, and the end of the pipe was 1,882 feet from the portal at the close of the shift on the 6th. The air in the tunnel had been good to 750 feet; this included 1-East and 1-West Drifts and 2-East and 2-West Drifts. Tees had been inserted in the air line at the intersection of these drifts, but it was not necessary to ventilate them. During this period the compressor was operated continually during the one working shift, air being delivered at the end of the pipe as it was connected. No attempt was made to support the pipe from the walls or back of the tunnel; it was merely laid along the bottom and at one side of the tunnel.

Bringing pipe into the tunnel manually was impracticable, and a burro was rented for this purpose. Because the tunnel floor proved too rough for a two-wheeled cart, a small metal sled was built to support the front end of the pipe. By experiment it was found that the most satisfactory load for the burro was two 21-foot lengths of pipe per trip. Later, as the distance from the portal increased, the round-trip time with the burro proved too great. It required 40 to 45 minutes for the burro to haul 42 feet of pipe 3,500 feet into the tunnel and return. The workmen could connect the lengths of pipe faster than the burro could haul it to them. A horse was rented to speed transportation of pipe, and this arrangement proved satisfactory. The horse could haul 7 lengths, or 147 feet, of pipe (the capacity of the sled) in less time. The horse was used to stock pipe at locations in the tunnel, and the burro was utilized for short hauls inside the tunnel. When enough pipe to complete the job was stockpiled in the tunnel, the horse was returned.

During the September 6 shift, a pocket of oxygen-deficient air was detected with a flame safety lamp 1,000 feet from the portal, between the end of the blowing air pipe and the portal. The workmen were kept out of the tunnel, and air was blown from the end of the pipe for 1 hour before the tunnel air became good throughout this distance. Later during the same shift, bad air was again detected at No. 3 Drift, 1,700 feet from the portal, again between the open end of the pipe and the portal. One hour was required to blow this out, also.

As the plugs in the tees inserted in the line had been drilled to allow a small quantity of air to blow at intervals into the tunnel, it was thought these might have exerted a slight back pressure against air exhausting toward the portal, thus causing the pockets of bad air. These were closed off. The compressor was shut off at the end of the shift with the end of the air line 1,882 feet from the portal.



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**TABLE 1. - Log of Operations, Ventilation of King Solomon Tunnel**

| Date | No. of men[1] | Compressor hours | Tunnel: Pipe laid, ft. | Tunnel: Distance from portal, ft.[2] | Laterals: Location | Laterals: Pipe laid, ft. | Other work | Remarks |
|---|---|---|---|---|---|---|---|---|
| Aug. | | | | | | | | |
| 22 | 2 | | | | | | | Foreman and compressorman hired. |
| 23 | 2 | | | | | | Foreman, compressorman to S.L.C. and return with compressor. | |
| 24 | 2 | | | | | | do. | Access road to portal rehabilitated. |
| 25 | 2 | | | | | | do. | |
| 28 | 2 | | | | | | Hauled 2,625 feet of 2 inch pipe from Leadville; set up compressor. | |
| 29 | 4 | | | | | | do. | Hired two laborers. |
| 30 | 4-1/2 | | | | | | Hauled pipe; set up compressor. | 4 hours. extra road work. |
| 31 | 4 | 8 | 765 | 681 | | | Hauled 2,100 feet of 2 inch pipe from Leadville. | 84 feet of pipe laid across dump. |
| Sept. | | | | | | | | |
| 1 | 4 | 8 | 315 | 996 | | | | Rented burro. |
| 5 | 4 | 8 | 483 | 1,479 | | | | |
| 6 | 4 | 8 | 403 | 1,882 | | | | Bad air at 1,000 ft. blown for 1 hr. |
| | | | | | | | | Bad air at 1,700 ft. blown for 1 hr. |
| 7 | 4 | 8 | -180 | 1,702 | | | Framed 1, 2, 3 Drifts for brattice | Removed pipe back to No. 3 Drift. |
| 8 | 4 | 8 | 327 | 2,029 | 3W.Dr. | 71 | Bratticed 2E, W, -3E, W Drifts and raises in 2E,W. Built door at portal. | Also removed 71 ft. pipe, 3W.Dr. |

See footnotes at end of table.



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TABLE 1. - Log of Operations, Ventilation of King Solomon Tunnel (Cont'd.)

| Date | No. of men[1] | Compressor hours | Tunnel: Pipe laid ft. | Tunnel: Distance from portal, ft.[2] | Laterals: Location | Laterals: Pipe laid, ft. | Other work | Remarks |
|---|---|---|---|---|---|---|---|---|
| Sept. 9 | 4 | 8 | 121 | 2,150 | | | Finished brattices; hauled pipe into tunnel. | Hired two extra compressormen. |
| 10 | 2 | 16 | | | | | Ran compressor day and night shifts. | Sunday. |
| 11 | 6 | 24 | 350 | 2,500 | 5E.Dr. | 21 | Bratticed 4E, W Dr. | |
| 12 | 5 | 24 | 450 | 2,950 | | | Finished bratticing. | |
| 13 | 5 | 24 | 250 | 3,200 | | | Bratticed 5E.Dr. | |
| 14 | 6 | 24 | 570 | 3,770 | 6E.Dr.<br>6W.Dr. | 21<br>108 | | Most of air diverted into 6E, W.Dr. on night shift. |
| 15 | 5 | 16 | | | 6W.Dr. | 60 | Hauled pipe into tunnel. | 6E, W.Dr. blown out graveyard. |
| 18 | 6 | 24 | 250 | 4,020 | 6W.Dr. | 294 | | Compressor started graveyard; air blown at 3,500 ft. and in 6W.Dr. |
| 19 | 6 | 24 | 436 | 4,456<br>(5,660) | 6W.Dr. | -483 | | Air good in 7E.Dr. - connected air line to old 2-1/2 inch pipe at 4,456 ft.; air blowing from end of 2-1/2 inch pipe, 5,660 ft., at end of shift. |
| 20 | 6 | 24 | | | | | | Air good at breast - air blowing at 5,660 ft. on three shifts. |
| 21 | 4 | 8 | | | | | | Blew air at 5,660 ft. and in 6E.Dr. |
| 22 | 4 | 8 | -1,000 | 3,456 | | | | Blew air at 3,456 ft. for 8 hr. |
| 25 | 4 | 8 | -1,000 | 2,456 | | | | Blew air from 3,456 to 2,456 ft. |
| Sept. 26 | 4 | 0 | -1,476 | 980 | | | Returned 2,688 ft. of pipe to Leadville. | No air delivered underground. |

See footnotes at end of table.



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TABLE 1. - Log of Operation, Ventilation of King Solomon Tunnel (Cont'd.)

| Date | No. of men[1/] | Compressor hours | Tunnel: Pipe laid, ft. | Tunnel: Distance from portal, ft.[2/] | Laterals: Location | Laterals: Pipe laid, ft. | Other work | Remarks |
|---|---|---|---|---|---|---|---|---|
| Sept. 27 | 4 | 0 | -980 | 0 | | | Took up 84 ft. pipe, dump; 2,583 ft. pipe returned to Leadville. | All pipe out of workings; no air delivered underground. |
| 28 | 2 | | | | | | Returned 1,764 ft. pipe to Leadville; loaded receiver, etc., in truck. | Returned burro. |
| 29 | 2 | | | | | | Delivered truck, compressor, tools, etc., to Denver. | Project completed. |

1/ Includes foreman.
2/ At end of shift.
(-) Indicates removal of pipe.



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To prevent a recurrence of the bad air found on the previous shift, 180 feet of pipe was removed on September 7. This allowed air to blow at 1,702 feet from the portal, the junction of the tunnel, and No. 3 Drifts. It was believed the bad air was entering the tunnel from these drifts. Although the air encountered in the first laterals had been good, it was not known how long it would remain so, as the air in the stopes and raises above these laterals was bad. It was unsafe for men to work with such conditions existing between them and their only exit at the portal. Slight variations in the atmospheric pressure or the turbulence at the junctions of the tunnel and these drifts of air currents moving toward the portal might suck bad air from these places and create similar pockets of bad air behind the men. To overcome such difficulties, it was decided to ventilate the laterals as they were reached, map and sample them immediately, and then brattice them tight.

Accordingly, Nos. 1, 2, and 3 Drifts were framed for brattice on September 7 and bratticed off September 8. It was necessary to lay 71 feet of pipe into No. 3 West Drift to clear it of bad air; this was removed during the same shift, and pipe in the tunnel was extended 327 feet to a point 2,029 feet from the portal.

An air door was built at the portal, and a small, gasoline-powered blower was installed on the surface. This exhausted air from the tunnel by means of an 8-inch ventilation pipe extended through the door frame into the tunnel and increased the rate at which air passed from the tunnel. Further to prevent the possibility of encountering pockets of bad air along the ventilated sections of the tunnel and to speed up ventilation generally, it was decided to run the compressor continually, even though work in the tunnel was carried out for only 8 hours of the day shift. Two additional compressor men were hired for the night and graveyard shifts. Though no work was performed in the tunnel on September 10, the compressor was operated continuously.

From September 10 until the breast of the tunnel was reached, with the compressor operating 24 hours each day and the laterals being ventilated and then bratticed as they were reached, the previous difficulties did not occur again. Air in the tunnel from the portal to the open end of the air line was tested at the beginning of each shift and in general was found to be satisfactory several hundred feet beyond the point the air was blowing. Usually this distance ahead of the open pipe was greater than the distance pipe could be laid during the shift. Thus, the men worked at laying pipe with good air a considerable distance ahead of them.

No difficulty was encountered at No. 4 East and West Drifts; the air cleared itself in them from the action of the air blowing in the tunnel. They were mapped, sampled, and bratticed, and pipe was laid in the tunnel to No. 5 East Drift. In here, the air had been enriched enough so that a carbide lamp could burn to the face (12.5 percent oxygen) but was not good enough to support a safety lamp (16.5 percent oxygen). One length of pipe (21 feet) was extended into this lateral, and a portion of the compressed air was blown in here the night of September 11. The air was good at the face at the start of the shift on September 12. It was mapped and bratticed.



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No. 6 East and No. 6 West Drifts intersected the tunnel at 3,500 feet from the portal. Oxygen-deficient air was present in both laterals. The air in them had cleared enough for a carbide lamp to burn along part of their length when the air line reached the junction of these laterals; however, it had not cleared sufficiently for a safety lamp to burn for any distance in the laterals.

The vein on which 6 East Drift was drivon was stoped to considerable height above the lateral, commencing about 20 feet east of the tunnel. The extent of stoping along the strike and up the dip of the vein could not be determined accurately as the hanging wall appeared loose and unsafe to work beneath. The stope above the drift was open, but rotten timber and broken rock had dropped into the drift and made it impassable. One length of pipe was laid into the entrance of the stoped area, and a portion of the air was blown in here. The air cleared enough for a safety lamp to burn in those areas of the stope that were accessible for sampling; however, it could not be determined whether the air in the entire stope became good.

The 6 West Drift was considerably longer and more crooked than the others encountered. It was necessary to lay 483 feet of pipe into this drift before the air at the breast was made good. Considerable time was consumed in bending the pipe to fit. The drift was partly blocked by rotten timber and loose rock that had fallen from a raise. These were cleared away, and the rest of the drift was ventilated without laying pipe.

While pipe was being laid in 6 West Drift, additional lengths were being connected in the tunnel beyond 3,500 feet. The air in this section had cleared a considerable distance ahead of the air line. Only a partial flow of air was blown in this section; the larger portion was diverted in 6 East and West Drifts. When No. 6 Drifts were mapped and sampled, the full amount of air again was blown ahead in the tunnel.

The laying of pipe in the adit tunnel continued without difficulty. On September 19, No. 7 East Drift was encountered at 4,456 feet from the portal. As this drift was approached with the air line, it became accessible with a carbide lamp. With the compressed air blowing at its junction into the tunnel, the drift became accessible with a flame safety lamp. In addition, the air in about 600 feet of tunnel ahead of the air line became accessible with a safety lamp, and a carbide lamp would burn several hundred feet farther.

At 4,456 feet in the tunnel, an old 2-1/2-inch air line, intact and hung from the back, was found. It extended ahead in the tunnel, its open end later being discovered at 5,660 feet from the portal. Two valves in this line were opened, and the 2-inch compressor line was connected to it. Air was blowing at 5,660 feet from the portal at the end of the September 19 shift. On September 20 the air was good to the breast of the tunnel, a distance of 5,728 feet from the portal. Nos. 8 and 9 Drifts were short, and the air in them became good as the air in the tunnel adjacent to them became good. On September 20, air was blown at 5,660 feet for 24 hours, until this far section of the tunnel had been mapped, but the compressor operation was cut to 8 hours on September 21. Thereafter its operation



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was confined to the 8-hour day shift, during which workmen removed pipe from the tunnel.

One thousand feet of pipe was removed on both September 22 and 25. The geologists, who had confined their work mainly to the laterals, worked in the adit tunnel, retreating ahead of the pipe crew. On September 26, 1,476 feet of pipe was removed. Only 980 feet of pipe remained in the tunnel, and the compressor was shut off permanently. The remainder of the pipe was removed September 27. The pipe was returned to Leadville. The compressor was returned to Denvel, Colo., on September 29, marking the completion of the project.

## SAMPLING AND TESTING OF TUNNEL AIR

The tunnel air was tested and sampled frequently to insure the protection of the workmen as they laid the pipe. The usual procedure was to test the oxygen content of the tunnel air by means of a flame safety lamp at the start of every working shift. Except in the two instances noted, the tunnel air from the portal to the end of the blowing air line would support a flame safety lamp. This indicated its oxygen content to be greater than 16.5 percent.

In only one other instance did the safety lamp even approach its extinguishing point in the distance between the portal and the end of the air line. This occurred on entering the tunnel at the start of the day shift, September 20. On this date, the flame became very feeble in the section of tunnel between 3,150 and 4,450 feet from the portal; however, it was not extinguished, and from 4,450 feet to the face of the tunnel the flame again became normal. At the end of the previous shift the 2-inch air line had been connected into the old 2-1/2-inch line at 4,450 feet, and the air was blown at 5,660 feet for 16 hours. The volume of oxygen-depleted air in this section of the tunnel, a distance of 1,200 feet, was a considerable larger amount than it had been attempted to move out or enrich previously. It is believed the 16-hour blowing period was insufficient to remove this volume from the tunnel or to enrich it sufficiently.

In routine testing of the air, it was found that a safety lamp would burn a considerable distance ahead of the open end of the air line. The safety lamp was therefore supported in the tunnel at this limit and in view of the workmen extending the pipe. They could thus observe any possible backing up of bad air. Usually, this distance that the lamp would burn ahead of the air line was greater than the length of pipe that could be laid during the shift, so that the pipemen worked a considerable distance behind the bad air. At various periods during the shift, the limit at which the safety lamp would burn was checked, and the lamp's position was moved forward as the oxygen content of the air ahead increased.

A carbide lamp was employed to test the air when it was desirable to investigate the tunnel for short distances beyond the limit of the safety lamp. A carbide lamp will burn in atmospheres containing 12.5 percent oxygen. This, of course, is too low for a workman except for very short periods; however, careful observation of the behavior of a carbide flame



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will allow one to stop considerably before the lower limit is reached. In general, the oxygen content of the tunnel air diminished gradually as the distance ahead of the air line increased. In only one or two instances was the oxygen content lowered abruptly.

Vacuum-bottle samples of the air were taken, usually at the farthest point investigated ahead of the air line. Usually these were taken at the start and close of each working shift. The analyses of these samples, their location, their distance from the air line, and other data are given in table 2.

Chemical-type oxygen and carbon dioxide indicators also were employed. These gave results comparable to those obtained with the flame safety-lamp, carbide-lamp, and vacuum-bottle samples and gave on-the-job analyses for carbon dioxide. Though tested for periodically, no carbon monoxide was indicated at any place in the tunnel.

A barograph installed at the portal recorded barometric pressire changes during the project. During this period the extremes in the barometric pressure were within 1 inch of each other; however, the changes were gradual, and the fluctuations generally remained within 1/2-inch limits. The surface temperatures and the underground temperatures varied considerably. Their effect and the effect of barometric pressure changes on the ventilation of the tunnel were not noticeable to any extent.

Outside temperatures ranged from below freezing to 62° F. during the working shift; however, the temperatures in the tunnel were nearly constant at 60° F. Relative humidity of the tunnel air was between 90 and 95 percent. The temperature of the air blowing from the compressor varied. As the pipe was extended, the blowing-air temperature increased nearly to that of the tunnel temperature. In general, it averaged 3 to 5° below the tunnel temperature. The volume of air delivered at the end of the open pipe at 5,660 feet from the portal was measured as 160 cubic feet per minute. The compressor registered 25 p.s.i. at the time this air measurement was taken.



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TABLE 2. - Data on air samples taken in King Solomon Tunnel

| Date | Hour | Sample location, ft. [1] | Air-line location, ft. [1] | Distance of sample from air line | Limit for safety lamp location, ft. [1] | Distance of safety lamp limit from air line, ft. | Analysis of tunnel air $CO_2$ | $O_2$ | $N_2$ |
|---|---|---|---|---|---|---|---|---|---|
| Jan. 19 | 2:30 pm | 800 | - | - | 800 | - | 0.83 | 16.91 | 82.26 |
| Sept. 1 | 9:15 am | 750 | 681 | 69 | 750 | 69 | .88 | 16.43 | 82.69 |
| 6 | 10:15 am | 1,680 | 1,580 | 100 | 1,680 | 100 | .93 | 14.67 | 84.40 |
| | 3:00 pm | 1,950 | 1,800 | 150 | - | - | .59 | 17.23 | 82.18 |
| 7 | 11:40 am | 2,100 | 1,900 | 200 | 2,100 | 200 | .73 | 15.76 | 83.51 |
| | 2:00 pm | 1,200 | 1,702 | -502 | 1,200 | -502 | .62 | 16.67 | 82.71 |
| 9 | 8:30 am | 2,500 | 2,029 | 471 | 2,500 | 471 | .92 | 14.38 | 84.70 |
| 11 | 10:00 am | 2,950 | 2,150 | 800 | 2,500 | 350 | .90 | 15.43 | 83.67 |
| | 2:30 pm | 2,910 | 2,430 | 480 | 2,500 | 70 | .79 | 15.86 | 83.32 |
| 12 | 8:00 am | 2,905 | 2,500 | 405 | 2,905 | 405 | .35 | 18.02 | 81.63 |
| | 2:20 pm | 3,500 | 2,853 | 647 | 3,500 | 647 | .83 | 14.66 | 84.51 |
| 13 | 8:45 am | 3,600 | 2,950 | 650 | 3,500 | 550 | .43 | 17.99 | 81.58 |
| | 3:00 pm | - | 3,192 | - | 4,000 | 818 | - | - | - |
| 14 | 9:00 am | 4,160 | 3,200 | 960 | 3,956 | 756 | .46 | 16.74 | 82.80 |
| | 3:50 pm | 4,456 | 2/ 3,770 | 698 | 3,950 | 180 | .66 | 14.22 | 85.12 |
| 15 | 8:45 am | 408 6WDr. | 10 6WDr. | 398 | 258 6WDr. | 248 | .54 | 16.83 | 82.63 |
| | 2:20 pm | 430 6WDr. | 80 6WDr. | 350 | 258 6WDr. | 178 | .91 | 14.90 | 84.19 |
| 18 | 9:00 am | 430 6WDr. | 80 6WDr. | 350 | 430 6WDr. | 350 | .68 | 16.74 | 82.58 |
| | 9:25 am | 4,960 | 2/ 3,770 | 1,190 | 4,456 | 686 | .35 | 15.24 | 84.21 |
| 19 | 9:05 am | 5,050 | 3/ 3,500 | 1,550 | 4,456 | 594 | .56 | 14.57 | 84.87 |
| 20 | 9:25 am | 5,728 | 4/ 5,660 | 68 | - | 68 | .07 | 20.87 | 79.06 |
| | 9:45 am | 33 9WDr. | 5,660 | 81 | - | 81 | .12 | 20.78 | 79.10 |

1/ Unless otherwise noted, is distance from portal.
2/ Majority of air blowing into 6E & W Drifts.
3/ Pipe extended to 4,020 feet in tunnel, but air blowing at 3,500 feet in tunnel and into 6W Drift.
4/ End of old 2-1/2-inch pipe.



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## COST SUMMARY

The costs of transporting a compressor and pipe to a property in order to perform a job similar to the one described would vary considerably. They would depend on the distance to be traveled, the size of compressor available, the amount of pipe needed, and other factors. Similarly, the amount of road rehabilitation and other preparatory work necessary would not be common to another undertaking but would vary with the particular property to be examined. For these reasons, the costs involved in transporting the equipment to the job, the wages paid during setting up of equipment, the amount expended on road rehabilitation, and other costs not comparable to similar projects are omitted in the cost summary of this project. The costs listed include no preparation work but begin August 31, the day pipe was first connected to the compressor and extended into the tunnel. The summary concludes September 27, the day on which the last length of pipe was removed from the tunnel.

Other than the foremen on the project, labor was obtained locally, and prevailing local wage rates were paid.

TABLE 3. - Summary of costs, King Solomon Tunnel project

A. Wages paid, August 31 to September 27

| Date | Number of employees (8-hour shifts) | | | Daily wages |
|---|---|---|---|---|
| | Foreman, $1.53 per hr. | Compressormen, $1.53 per hr. | Laborers, $1.40-1/2 per hr. | |
| Aug. 31 | 1 | 1 | 2 | $46.96 |
| Sept. 1 | 1 | 1 | 2 | 46.96 |
| 5 | 1 | 1 | 2 | 46.96 |
| 6 | 1 | 1 | 2 | 46.96 |
| 7 | 1 | 1 | 2 | 46.96 |
| 8 | 1 | 1 | 2 | 46.96 |
| 9 | 1 | 1 | 2 | 46.96 |
| 10 | - | 1 | - | 12.24 |
| 11 | 1 | 3 | 2 | 71.44 |
| 12 | 1 | 3 | 1 | 60.20 |
| 13 | 1 | 3 | 1 | 60.20 |
| 14 | 1 | 3 | 2 | 71.44 |
| 15 | 1 | 2 | 2 | 59.20 |
| 18 | 1 | 3 | 2 | 71.44 |
| 19 | 1 | 3 | 2 | 71.44 |
| 20 | 1 | 3 | 2 | 71.44 |
| 21 | 1 | 1/3 | - | 48.96 |
| 22 | 1 | 3 | - | 48.96 |
| 25 | 1 | 3 | - | 48.96 |
| 26 | 1 | 3 | - | 48.96 |
| 27 | 1 | 3 | - | 48.96 |
| | | | | $1,122.56 |

1/ Compressor operated only one shift through September 25 and then not at all. Laborers were terminated, and compressormen performed other duties but at former wage rate.



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TABLE 3. - Summary of costs, King Solomon Tunnel project (Cont'd.)

B. Materials and supplies

| Material | Amount and cost | | | Total cost |
|---|---|---|---|---|
| Prestone | 5 gal. | @ | $2.25/gal. | $11.25 |
| Vulco belts | 2 | @ | 3.18 ea. | 6.36 |
| Vulco belts | 2 | @ | 3.53 ea. | 7.06 |
| Waste | 5 lbs. | @ | 0.50/lb. | 2.50 |
| Brattice cloth | 2 rolls | @ | 0.33-1/2/sq. yd. | 69.68 |
| Lamp lighter flints | 12 | @ | 0.60/doz. | .60 |
| Carbide | 50 lbs. | @ | 9.80/cwt. | 4.90 |
| Cutting oil | 1 gal. | @ | 1.16/gal. | 1.16 |
| Pipe dope | 5 lbs. | @ | 0.60/lb. | 3.00 |
| Motor mend | 3 cans | @ | 1.50/can | 4.50 |
| Nails | 35 lbs. | @ | 0.12/lb. | 4.20 |
| Machine bolts | 3 | @ | 0.07 ea. | .21 |
| Safety hasp | 1 | @ | 0.30 ea. | .30 |
| Lumber | | | | 27.91 |
| Stovepipe | 10 lgths. | @ | 0.40/lgth. | 4.00 |
| Plaster | 1 sack | @ | 2.00/sack | 2.00 |
| Oats | 1 sack | @ | 3.85/sack | 3.85 |
| Hay | 8 bales | @ | 30.00/ton | 9.60 |
| Gasoline (fan & comp.) | 880 gal. | @ | 0.182/gal. | 160.16 |
| Gasoline (lamps) | 5 gal. | @ | 0.30/gal. | 1.50 |
| Motor oil | 31 gal. | @ | 0.84/gal. | 26.04 |
| Pressure lubricant | 5 lbs. | @ | 0.35/lb. | 1.75 |
| | | | | 352.53 |

C. Rentals

| | | | | |
|---|---|---|---|---|
| Burro | Duration of job. | | | $25.00 |
| Horse | 6 days | @ | $6/day | 36.00 |
| Total rentals | | | | 61.00 |
| Total cost of project. | | | | 1,536.09 |

## CONCLUSION

The foregoing data show that long adits and other underground workings having only one surface outlet can be ventilated with a relatively small volume of compressed air, provided the underground atmosphere consists of air deficient in oxygen only and does not contain concentrations of carbon dioxide or other gases difficult to dilute or remove; also provided the time element involved in ventilating the workings is not too essential.



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